the line joining the loci is perpendicular to the average direction of crossover planes. The crossover value for lines in any other directions would seem to be proportional to their *projections* on such a perpendicular. In short, both of Castle's alternative subsidiary hypotheses to account for the rarity of double crossovers are inconsistent with his primary assumption that distances are proportional to crossover values.

[1] These PROCEEDINGS, **5**, 1919, (25).

[2] Abnormal is a character that is separable from wild-type only under certain environmental conditions; and is also simulated by accidental abnormalities. It is, therefore, not a reliable character to use in linkage experiments.

[3] *Carnegie Inst., Washington, Pub.*, No. 237, 1916.

[4] Sturtevant, these PROCEEDINGS, **3**, 1917, (555), and Muller, *Amer. Naturalist*, **50**, 1916, (193, 284, 350, 421).

[5] Bridges, *J. Exp. Zool.*, **19**, 1915, (1), and Plough, *Ibid.*, **24**, 1917, (147).

[6] Bridges and Sturtevant, *Biol. Bull.*, **26**, 1914, (205), and Morgan and Bridges, loc. cit., note 3.

[7] That Castle tacitly recognized this is shown by the fact that he omitted lethal 2 from his model, without even mentioning the fact. It is obvious from an examination of the data in this case that the crossover values are inconsistent with those obtained in other experiments not involving lethal 2.

[8] Provided the relations of the loci are to be represented by straight lines joining them and proportional in length to the corresponding crossover values.

[9] It does not follow that 4.7 is to be taken as the locus of bifid, for the mean value indicated by all bifid experiments is the one most likely to coincide with future experiments; i.e., to give the best predictions.

[10] Castle concluded that the white forked value of 45.7, used by him, is somewhat too high, which is true; but there were available to him more than 40,000 flies (Bridges, *Genetics*, **1**, 1916, (1), and Weinstein, *Ibid.*, **3**, 1918, (135)) giving the lower value, in contrast to the less than 4000 flies on which the high value was based.

A COMPLETE APPARATUS FOR ABSOLUTE ACOUSTICAL MEASUREMENTS

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The apparatus here briefly described is the result of researches begun many years ago in the attempt to solve the problem of measuring the intensity of sound at any given point of space in terms of absolute units, by means of instruments that may be reproduced from specifications, and that shall be convenient and portable. For this purpose three things are requisite; first, a source of sound that shall continuously produce a simple tone of known intensity—this will be denoted by the term 'phone;' second, an instrument for measuring in absolute units a constantly maintained simple tone, here called

a 'phonometer;' third, in order to check the theory of the two instruments a series of experiments on the propagation of sound from one to the other, free from the effect of disturbing bodies. Such experiments must be made either in a room so padded as to absorb all sound, which is at present impossible, or else out of doors at a distance from all objects except the flat surface of the earth, of which the coefficient of reflection is measured. This has been the method here pursued. While many observers have attacked one or both of the instrumental problems, it is not known that any has previously attacked all three parts above mentioned.

1. Phonometer.—In order to attain the required sensitiveness for the small amount of energy concerned, it is necessary to use the principle of resonance, and a coupled system of two degrees of freedom is used, the first consisting of a tunable air resonator, the second, of a tuned diaphragm which is to make the motion visible. Inasmuch as the sensitiveness will ultimately depend on the damping intrinsically residing in the diaphragm, it is desirable to reduce this as much as possible. For many years the best thing found was a glass diaphragm, tuned by adding weights. Finally it was found that mica diaphragms could be had having a smaller damping than glass. Finally, however, after an attempt to measure the loudness of some of the fog-signals on the Maine coast, all of which have different pitches, it was found necessary to have a diaphragm susceptible of gradual tuning, which could not be obtained by variation of mass. Accordingly the instrument was entirely redesigned, and the tuning was done by varying the potential, rather than the kinetic energy of the diaphragm, by stiffening it with a string tuned by tension. And now the chief improvement was made of abolishing the diaphragm, and since the resonator has a hole for the sound to enter, it was determined to replace the diaphragm by a rigid piston placed centrally in the hole, leaving an annular aperture for the sound to enter, and at the same time freeing us from the necessity of using the calculated equivalent area of the diaphragm. These improvements are embodied in the instrument shown in Figs. 1 and 2.

The phonometer is shown in elevation in Fig. 1, where 1 is the cylindrical resonator, sliding in the cylindrical piece screwed to the main casting A, resting on two feet and the cylinder 8. The end of the resonator is closed by a glass window 15. For years all measurements were made by the Michelson interferometer viewed stroboscopically, as it was desired to have the diaphragm absolutely free to move. For purposes of portability and convenience this has now been given up, and replaced by observing in a telescope the displacement of a mirror, as in Max Wien's phonometer. The interferometer, 14, (not shown) is attached temporarily at the front, or receiving end, to check the indications of the mirror. In the micrometer eyepiece, 2, adjustable with five degrees of freedom, is observed the image of the filament of the small lamp 4, fed through a key 5 by three dry cells, 10, placed in the cylindrical holder upon which the tube 7 is carried by a bayonet joint. The

vertical image of the filament is drawn out into a horizontal band. Details are shown in Fig. 2. The aluminium disk 12 is hung in the center of the hole in the front plate by means of the three steel wires clamped at one end by the spider 13, and at the other wound on the pins 8, turned by a key from the

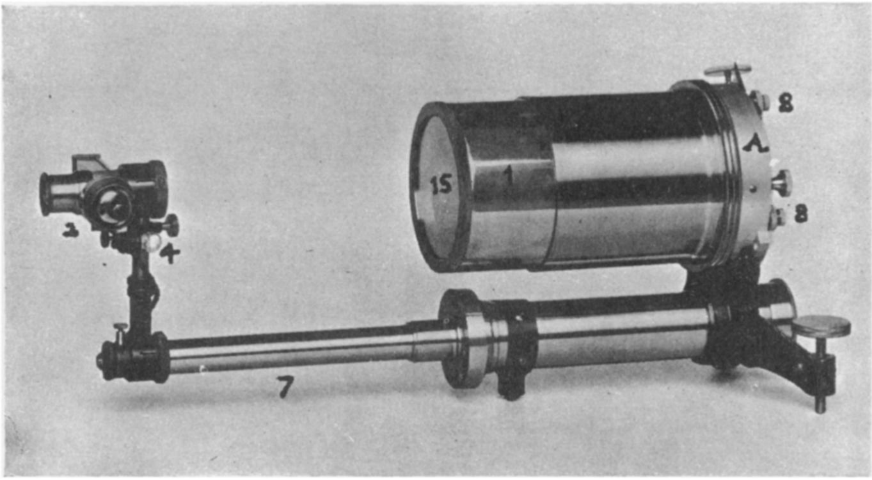
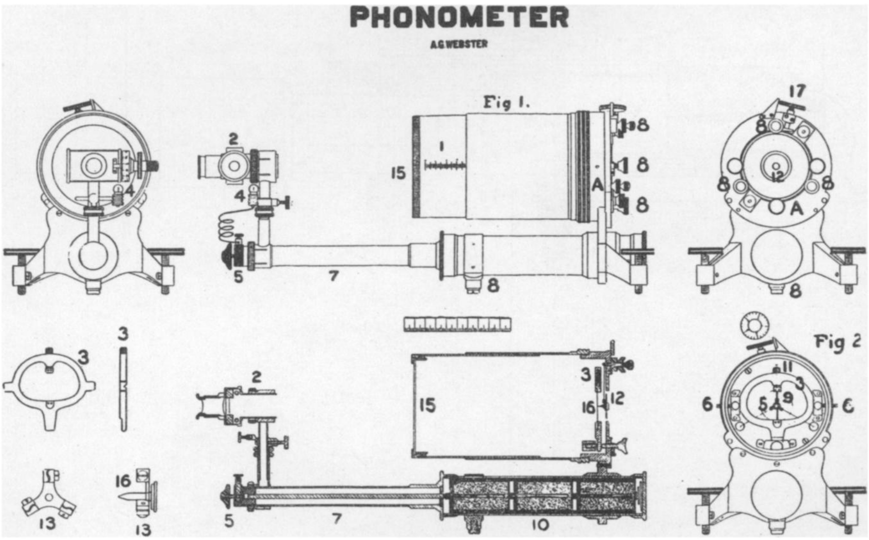


FIG. 1 A



FIGS. 1 and 2

outside, one controlled micrometrically by a lever and screw 17, by which the fine tuning is done. The wires pass over either one of two sets of three bridges cast on the front plate. The objective of the telescopic observing device is

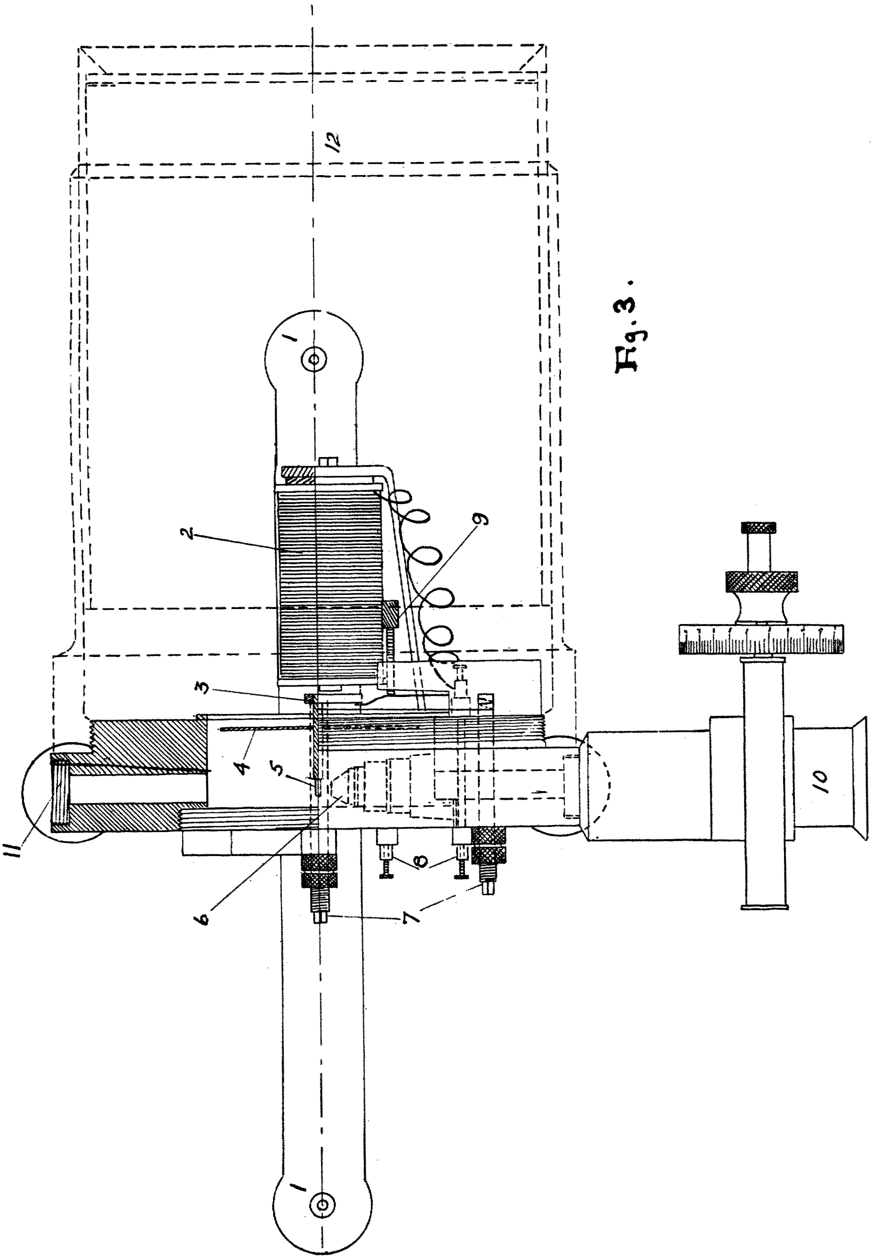


Fig. 3.

the small concave mirror 5, the back of which constitutes its own short lever, being directly pushed by a point 16 carried by the spider 13, which carries the disk 4. Instead of being pivoted in jewels, the mirror is carried by a torsion strip 9, cut from thin sheet steel with a square side projection upon which the mirror 5 is cemented. The strip is held by end clamps, and its tension may be adjusted by a screw 11, bearing on the spring 10, (inside). Two micrometric adjustments are secured by the strip being carried on a rocker 3, pivoted on two screws 6, allowing of sidewise displacement in order

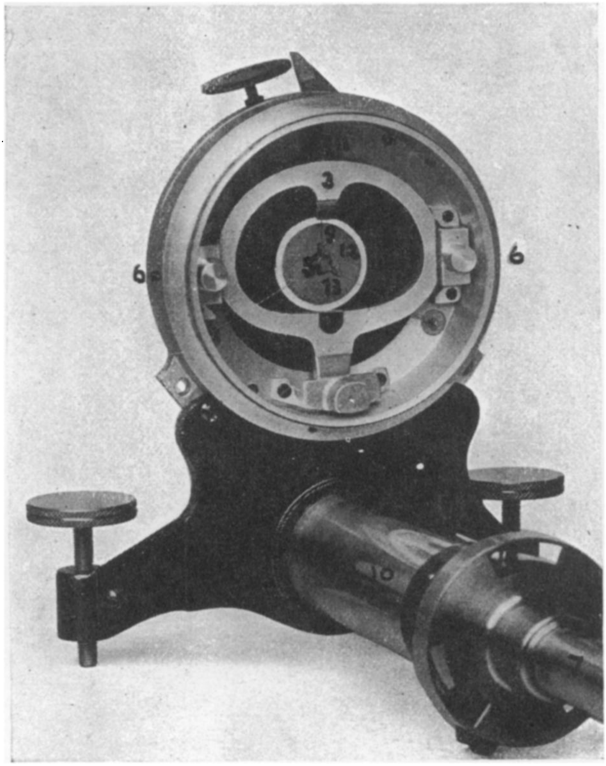


FIG. 2A

to change the lever arm of mirror 5, and thus the magnification of the motion. The motion of the image sidewise in the field of the ocular is obtained by a slow motion of the rocker, controlled by a screw at its lower end, accessible from outside. All other adjustments of the image are made at the ocular end. With the usual leverage of one-fourth to one-third of a millimeter between the point and the axis of the mirror, and a distance of forty centimeters to the reticule in the ocular, a magnification of about 2400 is obtained, and as one can read to one-tenth of a millimeter on the reticule, we may detect a dis-

placement of 1/24,000 millimeter of the vibrating disk, which is of the same order as could be used with the interferometer, and far better than could be done with a microscope. This phonometer is as sensitive as the normal ear (but for a very limited range).

2. Phone.–The phone, after having gone through many different forms, has now assumed a form closely connected with the phonometer, particularly as to the possibility of tuning. Fig. 3 shows the form now chiefly used. The disk 3, placed centrally in the hole of the resonator, supported in its wires and tuning pins 7, is actuated by an electromagnet 9, the current of which is inter-

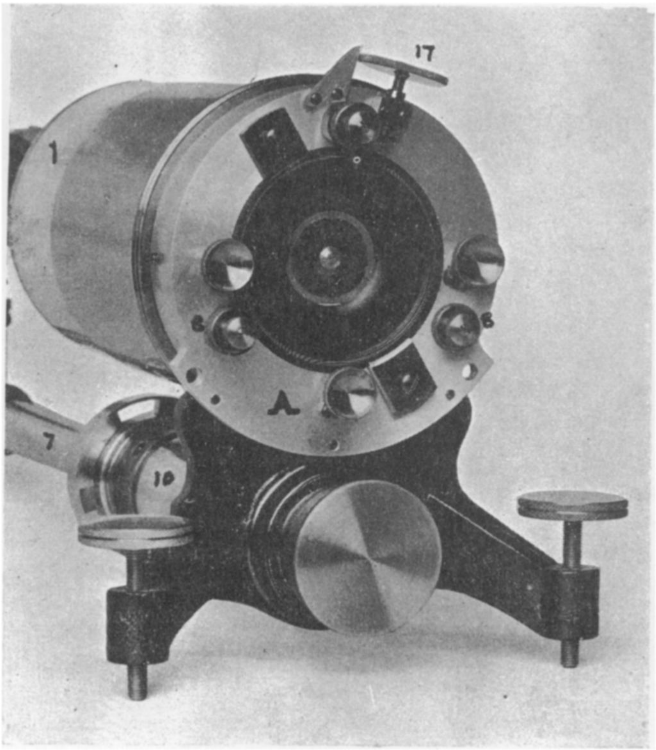


FIG. 2B

rupted by a separate electrically-maintained tuning-fork with a platinum point dipping into mercury. If exact purity of sound is not important, and the slight fizzing always associated with a dry contact is unobjectionable, a spring interrupter may be used, and the phone is self-contained, but generally it is better to have a set of forks to be used in the interchangeable stand, to control the phone at various pitches.

During the last year I have made the acquaintance of the pliotron and found it to be a wonderfully convenient instrument for the production of

harmonically varying currents. I accordingly adopted it instead of the interrupting tuning fork, inasmuch as it could be instantaneously tuned to any pitch whatever, and we are therefore freed from the necessity of being confined to four or five pitches, but have perfectly continuous range. The intensity of the sound emitted is measured by the amplitude of vibration of the disk, read off by the micrometer 10, focused on a fine slit ruled in the silvering of a piece of cover-glass 5 carried by the disk, and illuminated by an incandescent lamp and condenser not shown. It may be remarked that this phone as it stands may be used as a phonometer for tolerably loud sounds, such as those of singing near by, which gives a considerable vibration in the microscope. It should be likewise stated that this phone produces sound more efficiently than any other known instrument.

The *theory* of the phonometer and the phone is given in another paper.